

## VOICE-ACTIVITY DETECTION USING ENERGY RATIOS AND PERIODICITY

### Technical Field

This invention relates to signal-classification in general and to  
5 voice-activity detection in particular.

### Background of the Invention

Voice-activity detection (VAD) is used to detect a voice signal in  
a signal that has unknown characteristics. Numerous VAD devices are  
known in the art. They tend to follow a common paradigm comprising a  
10 pre-processing stage, a feature-extraction stage, a thresholds comparison  
stage, and an output-decision stage.

The pre-processing stage places the input audio signal into a  
form that better facilitates feature extraction. The feature-extraction stage  
differs widely from algorithm to algorithm, but commonly-used features  
15 include (1) energy, either full-band, multi-band, low-pass, or high-pass, (2)  
zero crossings, (3) the frequency-domain shape of the signal, (4)  
periodicity measures, and (5) statistics of the speech and background  
noise. The thresholds comparison stage then uses the selected features  
and various thresholds of their values to determine if speech is present in  
20 or absent from the input audio signal. This usually involves use of some  
"hold-over" algorithm, or "on"-time minimum threshold, to ensure that  
detection of either presence of speech lasts for at least a minimum period  
of time and does not oscillate on-and-off.

Some known VAD methods require a measurement of the  
25 background noise a-priori in order to set the thresholds for later  
comparisons. These algorithms fail when the acoustics environment  
changes over time. Hence, these algorithms are not particularly robust.  
Other known VAD methods are automatic and do not require a-priori  
measurement of background noise. These tend to work better in changing  
30 acoustic environments. However, they can fail when background noise

has a large energy and/or the characteristics of the noise are similar to those of speech. (For example, the G.729 VAD algorithm incorrectly generates "speech detected" output when the input audio signal is a keyboard sound.) Hence, these algorithms are not particularly robust  
5 either.

### **Summary of the Invention**

This invention is directed to solving these and other problems and disadvantages of the prior art. Generally, according to the invention, voice activity detection uses a ratio of high-frequency signal energy and  
10 low-frequency signal energy to detect voice. The advantage of using this measure is that it can distinguish between speech and keyboard sounds better than simply using high-frequency energy or low-frequency energy alone. Preferably, voice activity detection further uses a periodicity measure of the signal. While a periodicity measure has been used in  
15 speech codecs for pitch-period estimation and voiced/unvoiced classification, it is used here to distinguish between speech and background noise. Also preferably, voice activity detection further uses total signal energy to detect voice. Significantly, however, no initial decision about detection is based on the total energy level alone. This  
20 makes the detection less susceptible to non-speech changes in the acoustic environment, for example, to volume changes or to loud non-speech sounds such as keyboard sounds. Furthermore, this makes it possible to use the detection for very low-energy speech, which in turn makes the detection more robust in situations where a poor-quality  
25 microphone is used or where the microphone recording-level is low.

Specifically according to the invention, voice activity detection involves determining a difference between (a) an average ratio of energy above a first threshold frequency in a signal--illustratively the signal energy between about 2400 Hz and about 4000 Hz--and (b) energy below  
30 the first threshold frequency in the signal--illustratively the signal energy

between about 100 Hz and 2400 Hz--and (b) a present ratio of the energy above the first threshold frequency in the signal and energy below the first threshold frequency in the signal, and indicating that the signal includes a voice signal if the difference is either exceeded by a first threshold value  
5 or exceeds a second threshold value that is greater than the first threshold value. Preferably, the noise energy--illustratively, energy in the signal below about 100 Hz--is removed from the signal prior to the determining, so as to eliminate effects of noise energy on voice activity detection.

Preferably, the voice activity detection further involves  
10 determining the average periodicity of the signal, and indicating that the signal includes a voice signal if the average periodicity is lower than a third threshold value. Illustratively, determining the average periodicity involves estimating a pitch period of the signal, determining a gain value of the signal over the pitch period as a function of the estimated pitch period, and  
15 estimating a periodicity of the signal over the pitch period as a function of the estimated pitch period and the gain value.

Further preferably, the voice activity detection further involves determining a difference between an average total energy in the signal--illustratively the total energy in the voiceband from about 100 Hz to  
20 about 4000 Hz--and present total energy in the signal, and indicating that the signal includes a voice signal if the difference between the average total energy and the present total energy exceeds a fourth threshold value and the average periodicity of the signal is lower than a fifth threshold value.

25 Further preferably, the voice activity detection is performed on successive segments of the signal--illustratively on each 80 samples of the signal taken at a rate of 8KHz. If there is not an indication that voice has been detected in the present segment but there is an indication that voice has been detected in the preceding segment, a determination is  
30 made of whether the average total energy of the signal exceeds a minimum average total energy of the signal by a sixth threshold value. If

so, an indication is made that a voice signal has been detected in the present segment of the signal.

While the invention has been characterized in terms of method steps, it also encompasses apparatus that performs the method steps.

5 The apparatus preferably includes an effector--any entity that effects the corresponding step, unlike a means--for each step. The invention further encompasses any computer-readable medium containing instructions which, when executed in a computer, cause the computer to perform the method steps.

10 These and other features and advantages of the present invention will become more apparent from the following description of an illustrative embodiment of the invention considered together with the drawing.

### **Brief Description of the Drawing**

15 FIG. 1 is a block diagram of a communications apparatus that includes an illustrative implementation of the invention;

FIG. 2 is a block diagram of a voice-activity detector (VAD) of the apparatus of FIG. 1;

20 FIG. 3 is a functional block diagram of a thresholds comparison block of the VAD of FIG. 2; and

FIG. 4 is a functional block diagram of an output decision block of the VAD of FIG. 2.

### **Detailed Description**

25 FIG. 1 shows a communications apparatus. It comprises a user terminal 101 that is connected to a communications link 106. Terminal 101 and link 106 may be either wired or wireless. Illustratively, terminal 101 is a voice-enabled personal computer and VoIP link 106 is a local area network (LAN). Terminal 101 is equipped with a microphone 102 and speaker 103. Devices 102 and 103 can take many

forms, such as a telephone handset, a telephone headset, and/or a speakerphone. Terminal 101 receives an analog input signal from microphone 102, samples, digitizes, and packetizes it, and transmits the packets on LAN106. This process is reversed for input from LAN 106 to speaker 103. Terminal 101 is equipped with a voice-activity detector (VAD) 100. VAD 100 is used to detect voice signal received from microphone 102 in order to, for example, implement silence suppression and to determine half-duplex transitions.

According to the invention, an illustrative embodiment of VAD 100 takes the form shown in FIG. 2. VAD 100 may be implemented in dedicated hardware such as an integrated circuit, in general-purpose hardware such as a digital-signal processor, or in software stored in a memory 107 of terminal 101 or some other computer-readable medium and executed on a processor 108 of terminal 101. Illustratively, the analog output of microphone 102 is sampled at a rate of 8K samples/sec. and digitized by terminal 101. VAD 100 receives a stream 200 of the digitized signal samples and performs serial-to-parallel (S-P) conversion 202 thereon by buffering the samples into frames of N samples, where N is illustratively 80. The frames are then passed through a high-pass filter 204 to remove therefrom noise caused by the equipment-in-use or the background environment. Filter 204 is illustratively a 10<sup>th</sup> order infinite impulse response (IIR) filter with a cut-off frequency around 100 Hz. The filtered frames are then distributed to components of a feature-extraction stage for computation of the following parameters: periodicity, total voiceband energy, and a high-low frequency energy ratio.

#### Periodicity

The periodicity calculation involves first estimating a pitch period (T) 206 of the speech signal. Pitch-period estimation is known in speech processing. The illustrative method used here may be found in

L.R. Rabiner and R.W. Schafer, Digital Processing of Speech Signals, Prentice Hall, Englewood Cliffs, N.J. (1978), pp. 149-150. The value of pitch period  $T$  that minimizes the average magnitude difference function below is calculated as:

$$S(T) = \frac{1}{T} \sum_{n=0}^T |x[n] - x[n-T]|$$

where  $x[n]$   $n=0, 1 \dots N-1$  is the input signal to pitch period 206 calculation.

This is computed for  $T = T_{\min}, T_{\min} + 1, \dots, T_{\max}$ . The constants  $T_{\min}$  and

$T_{\max}$  are the lower and upper limits of the pitch period, respectively. The

10 values chosen here are 19 and 80. The value that minimizes the above function is represented as  $T_{opt}$ . After finding  $T_{opt}$ , a periodicity (C) 208 is

illustratively computed in a similar way to computation of the pitch

prediction filter parameters used in speech codecs and detailed in R.A.

Salami et al., "Speech Coding", Mobile Radio Communications, R. Steele

15 (ed.), Pentech Press, London (1992) pp. 245-253. A gain value ( $A$ ) is computed as:

$$A = \frac{\sum_{n=0}^{T_{opt}-1} x[n]x[n-T_{opt}]}{\sum_{n=0}^{T_{opt}-1} [x[n-T_{opt}]]^2}$$

The periodicity  $C$  is then given by:

$$C = \frac{\sum_{n=0}^{T_{opt}} [x[n] - Ax[n-T_{opt}]]^2}{\sum_{n=0}^{T_{opt}} [x[n-T_{opt}]]^2}$$

20 When the signal is fully periodic,  $C$  is 0. Conversely, when the signal is random,  $C$  is 1.

Total voiceband energy

The total voiceband energy ( $E_f$ ) 214 is computed for the voiceband frequency range from 100 Hz to 4000 Hz. The total voiceband energy in decibels is given by:

$$5 \quad E_f = 10 \log_{10} \left[ \frac{1}{N} \sum_{n=0}^{N-1} x[n]^2 \right]$$

where  $x[n]$   $n = 0, 1, \dots, N - 1$  is the input signal to total voiceband energy 214 calculation.

High-low frequency energy ratio

10 Energy ratio ( $E_r$ ) 224 is computed as the ratio of energy above 2400 Hz to the energy below 2400 Hz in the input voiceband signal. To obtain the high-frequency signal, the output of high-pass filter 204 is passed through a second high-pass filter 220 that has a cut-off frequency of 2400 Hz. The energy in decibels of the high-frequency signal is given by:

$$15 \quad E_h = 10 \log_{10} \left[ \frac{1}{N} \sum_{n=0}^{N-1} x_h[n]^2 \right]$$

where  $x_h[n]$  is the signal output by high-pass filter 220. The high-low energy ratio ( $E_r$ ) 224 is then given by:

$$E_r = \frac{E_h}{E_f - E_h}$$

where  $E_f$  is the total voiceband energy 214.

20 To make the algorithm operate automatically, initial values of the parameters  $E_f$ ,  $E_r$ , and  $C$  are computed for the first  $N_i$  frames that enter VAD 100 following initialization. Here  $N_i$  has been chosen as 32. During this stage of computation, the minimum value of  $E_f$  is computed and is denoted as  $E_{min}$ . For every subsequent frame, running  
25 averages 212, 218, 228 are used together with smoothing of the

parameters to make the algorithm less sensitive to local fluctuations. For the total voiceband energy and the energy ratio, differences 216 and 226, respectively, between the smoothed frame values and the running averages are computed. These are denoted by  $\Delta E_f$  and  $\Delta E_r$ . The

5 minimum energy value  $E_{min}$  is also updated, illustratively every 20 frames.

After feature extraction, a comparison of the parameters is made with several thresholds to generate an initial VAD ( $I_{VAD}$ ), at thresholds comparison block 230. The procedure for this is illustrated in the flowchart of Figure 3. Essentially, four different comparisons are made  
10 based on the smoothed periodicity  $C_s$ , energy difference  $\Delta E_f$ , and energy-ratio difference  $\Delta E_r$ . Comparisons 304 and 306 are for detecting voiced/periodic portions of speech. Comparisons 310 and 312 are for detecting unvoiced/random portions of speech.

Threshold comparison 230 is performed anew for every frame  
15 processed by VAD 100. Upon startup of thresholds comparison 230, at step 300 of FIG. 3, the value of  $I_{VAD}$  is initialized to zero, at step 302. A set of four comparisons is then made at steps 304, 306, 310, and 312. A comparison is made at step 304 to determine if  $\Delta E_f < -7dB$  and  $C_s < .5$ ; if so, voiced speech has been detected, as indicated at step 308; if not, speech has not been detected, as indicated at step 318. A comparison is made at step 306 to determine if  $C_s < 0.15$ ; if so, voiced speech has been detected, as indicated at step 308; if not, speech has not been detected, as indicated at step 318. A comparison is made at step 310 to determine if  $\Delta E_r < -10$ ; if so, unvoiced speech has been detected, is indicated at  
20 step 314; if not, speech has not been detected, as indicated at step 320. A comparison is made at step 312 to determine if  $\Delta E_r > 10$ ; if so, unvoiced speech has been detected, as indicated at step 314; if not, speech has not been detected, as indicated at step 320. If speech has been detected by any one or more of the comparisons 304, 306, 310, and 312, the value of  
25  $I_{VAD}$  is set to one, at step 316; if speech has not been detected by any of  
30



the comparisons, the value of  $I_{VAD}$  remains zero. Thresholds comparison block 230 then ends, at step 322.

After thresholds comparison 230 has been made to determine the value of  $I_{VAD}$ , a final output decision is made at block 232. A flowchart  
 5 describing this block is shown in FIG. 4. Output decision 232 is performed anew for every value of  $I_{VAD}$  produced by threshold comparison 230.

Upon startup of VAD 100, the values of a holdover flag  $H_{VAD}$  and a final VAD flag  $F_{VAD}$  are initialized to zero, at step 400. Upon receipt of an  $I_{VAD}$  value from block 230, at step 402, output decision 232 checks  
 10 whether the received value of  $I_{VAD}$  is one, at step 404. If so, it means that speech has been detected, as indicated at step 406. Output decision 232 therefore sets  $H_{VAD}$  to one, at step 408, and sets  $F_{VAD}$  to one, at step 418. The value of  $F_{VAD}$  constitutes output 234 of VAD 100. If the value of  $I_{VAD}$  is found to be zero at step 404, speech has not been detected, as indicated  
 15 at step 409. However, output decision 232 checks if the value of  $H_{VAD}$  is set to one from a previous frame, at step 410. If so, output decision 232 further checks if the smoothed value of  $E_f$  less the value of  $E_{min}$  is greater than 8dB, at step 412. If so, holdover is indicated, at step 414, and so output decision 232 maintains  $F_{VAD}$  set to one, at step 418, even though  
 20 speech has not been detected. If the value of  $H_{VAD}$  is found to be zero at step 410, or if the difference between the smoothed energy and the minimum energy computed at step 412 has fallen to less than 8dB, speech is not detected and there is no hold-over, as indicated at step 415. Output decision 232 therefore sets the values of  $H_{VAD}$  and  $F_{VAD}$  to zero, at  
 25 step 416. Following step 416 or 418, output decision 232 ends its operation, at step 420, until the next  $I_{VAD}$  value is received at step 402.

Of course, various changes and modifications to the illustrative embodiment described above will be apparent to those skilled in the art. For example, the noise-energy filter may be dispensed with. A different  
 30 value may be used for the high/low frequency threshold. Sampling of the input signal may be affected at a different rate, especially at higher rates.

The uppermost frequency of the voice band is subsequently increased. The holdover may be dispensed with and the initial VAD output  $I_{VAD}$  may be used as the final VAD output. A different procedure may be used to estimate the pitch period or, the combined threshold comparison of the energy and periodicity may be replaced with a single energy threshold comparison. Such changes and modifications can be made without departing from the spirit and the scope of the invention and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be covered by the following claims except

10 insofar as limited by the prior art.